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QUALITY OF THE URBAN AIR AND THE CLIMATE CHANGE

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Abstract
The aim of this paper is to give conceptual background for the climate impact assessment on those meteorological factors which determine the physiological effects and the quality of ambient air in urban environment. In this context, the principal consequences of the global climate change are dealt with, and the possibly modifying elements of urban climate and urban air quality are considered and illustrated for the case of the Hungarian capital.

INTRODUCTION

> "Before the advent of individual and collective environmental consciousness leading to the gradual improvement in many aspects of air quality, man had discharged vast quantities of waste products into the air from house and factory chimneys and plant, and from quarries, cars, lorries, trains and ships." (Chandler, 1976)

With the rapidly increasing, anthropogenically enhanced, atmospheric concentration of the greenhouse gases, the risk of unprecedentedly rapid climate change is more and more threatening. This change is frequently called inadvertent, however, awareness on the greenhouse effect of some human activities goes back to the past century. Whatever the reasons of these changes in the global climate system, the implications might appear in all components of the system, on all spatial and temporal scales and for the multitude of climate-sensitive components of environment and socioeconomic activities.

The smaller the scale of impact of the global processes, the more complex is the procedure of its evaluation and the more uncertain of its estimate. The possible effects of the global change on mesoscale phenomena, and in particular, on the urban climate and air quality are hardly assessable. Besides the increasing levels of uncertainties in the estimation "cascade" (from global to local phenomena), there are much more regional and local environmental and societal factors which contribute to the formation of specific character of the urban climate and should be taken into account in climate change analysis.

The impacts of the changing global state of climate on the urban air can be categorized in two more or less related to each other sets: in the impacts on the climatic features, and in the impacts on the chemical composition of air in the urban environment. Since these processes may interact (as, for instance, some meteorological elements influence the chemical reactions), it is also reasonable to introduce the term of the combined effects of the global change on the ambient air of the citizens. In turn, these changes will have their ecological, physiological and other impacts, so that one can differentiate among the first, second or third order climatic impacts. Of these further implications of the changing urban air properties, the impacts on the human health are of highest significance.

The potential regional effects of climate change on economic sectors – water management, agriculture, forestry and energy sector for example – have been intensively investigated in recent decades. Such areas have attracted great attention like the effects on environment as a whole, whilst much less attention was paid to the possible impacts on air quality and health. In Hungary, recent climatological research in the context of global warming is also directed to the problems of regional climatic implications and their impacts on the above-mentioned areas (Czelnai, 1980; Antal and Glantz, 1988; Mika, 1988; Práger and Pálvölgyi, 1989; Götz, 1990; Faragó, Iványi and Szalai, 1990, Antal and Starosolszky, 1990). It does not mean that the issues of environmental quality are not of high concern presently in the country; air quality problems of the capital, in some parts of which the situation is rather bad because of the high emission rates of pollutants from different sources, are receiving much attention. The supposed effects of climate change will add to these problems, occasionally creating even more "favorable" conditions for the accumulation of the toxic pollutants in the air and causing higher environmental discomfort.

GLOBAL CLIMATE CHANGE AND REGIONAL EFFECTS

Global scenarios and uncertainties in forcing rates are significant factors affecting responses to potential adverse effects of climate change. There is no clear evidence yet that the Earth climate is presently undergoing an unprecedented rapid change, however, the increasing atmospheric content of certain greenhouse gases should be considered as growing risk of such global and occasionally irreversible change. The uncertainty originates from both the limited ability of the climatic models to simulate and predict the behavior of the climate system, and the fact that recent increases in mean global temperature are still within the range of natural variability.

˙There[1] is an about 0.5°C increase in the global mean surface temperature during this century which magnitude is of the same order as that of the natural climate variability). According to different estimates, the doubling of greenhouse gases over the pre-industrial levels, or more exactly, the doubling of their direct radiative forcing potential is expected between 2025-2060 for a 'business-as-usual' scenario, i.e. with no overall changes in controlling the human-induced emissions of the greenhouse gases. This would mean a rate of increase of global mean surface temperature of about 0.3°C per decade, therefore, 1°C increase by 2025 and a 3°C warming by the end of the next century, respectively. The change in the surface air temperature and other climatic elements will significantly differ for the various geographical areas.

˙There are considerable uncertainties about the expected features of the changing climate. The primary reason of these uncertainties is that we have limited ability to predict the future anthropogenic emission rates of the greenhouse gases or the rates of the further burning of the tropical forests which are important sinks of atmospheric carbon dioxide. Another problem is the extremely complicated structure and interaction of the components of the climate system. It means that the present numeric models can reproduce only the main features of the past, present or future climate to some extent. Further improvement and details of picture on the expected future behavior of the global climate can be provided with the inclusion of more realistic submodels of ocean and cryosphere or through the more realistic description of the specific role of biosphere in global cycle and balance of some atmospheric components.

˙As concerns those elements of forcing mechanisms which are controllable in principle, conditional estimates are derived which are based on different assumptions about the future emission trends. Depending on implementation of the alternative response strategies of emission reductions, a wide range of estimates on the future transient and equilibrium climate state is deduced with the general scientific consensus that the latter would correspond to the 1 to 5°C temperature increase by the end of the next century. Obviously, such approach is straightforward for stimulation of the decision-making process as regards the various measures to cut the emissions of the greenhouse gases and to force the acceptance of the 'business-as-unusual' strategy in environmentally consciousness development.

The possible regional implications of global climate change are even more uncertain. By means of the dynamic models and cautiously used teleconnections (relating the macroscale and local climatic parameters), estimates have been deduced for various regions. In particular, higher

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[1] Paragraphs labeled by ˙ are part of the paper as included in the proceedings, but were not included in conference document published later by the Climate Institute.

temperature increase than that for the global average and the reduction of the summer precipitation is expected for Southern Europe (IPCC-WG-I, 1990). The change will also have an expressed seasonal character in this region; it means considerably milder winters, and longer, warmer and drier summers. Finer estimates have been elaborated for the Central European region – the Carpathian basin and especially, for the area of Hungary – in order to accomplish more specific impact studies. These studies show also: the amplification of the global temperature rise for the region with a much higher factor during the winter period; the reduction of the summer precipitation (at least for the moderate equilibrium global warming); and the increase of solar radiation. All these are related to changes in the circulation patterns and cloudiness: less intense zonality during the winter period and decrease in the average cloudiness during the summer period (Mika, 1988, 1989; Faragó, Iványi and Szalai, 1990; Mika and Pálvölgyi, 1991).

Based on the assumption that the relations revealed from the past observations for the parameterization of models or estimating the global-regional teleconnections have only a very limited scope beyond the past range of climatic variations, more detailed estimates are derived for a 'low' scenario, namely, for the large-scale temperature rise of +0.5°C (in the Northern Hemisphere). According to these estimates, the winter temperature rise is of similar magnitude while the relative warming during the summer half-year may even exceed the large-scale warming rate by one and a half times. Simultaneously, summer half-year precipitation is expected to decrease in the region by about 10%, with similar order of increase in the global radiation and length of periods with sunshine (Mika, 1989).

In addition to the expected change in the climatic characteristics, we should not forget about the origin of this problem; the increasing amount of the greenhouse gases and other pollutants in the atmosphere does not only contribute to the climate change, but it has also its direct effect on the air quality. These effects strongly differ for the particular releases, their radiative properties, chemical reactions, residence time in the atmosphere and scale levels of impacts. Some of these gases are critical for global greenhouse effect, solid (aerosol) pollutants even counteract to this phenomenon to some extent, and other releases play significant role in determining air quality. Because, large cities are also the intensive sources of some of these pollutants, and these releases and the related reactions may be influenced by the changing climatic conditions, for the adequate assessment of the tendencies in the quality of ambient air in urban areas, these processes should also be taken into consideration.

CHARACTERISTICS OF URBAN AIR AND THE LARGE-SCALE CLIMATIC PROCESSES

The impacts of the climate change on urban air quality can be properly evaluated only if those principal local- or mesoscale attributes and parameters of the atmospheric environment are identified first, which "transmit" the large-scale effects. Moreover, the main general properties of the urban climate should be described because the consequences of the climate change will add (or superposed) to this "base" level. This analysis is necessary not only for the assessment of the perspectives of the urban environmental conditions, but it is also unavoidable for attempts to detect or separate the global impacts. The latter problem is especially critical for the urban areas because both the heat island phenomenon (and the related thermal comfort) and air pollution have considerable secular changes independent of global change. The magnitude of the local-scale fluctuations and long-term tendencies in the urban environmental characteristics which are attributable to local forcing significantly exceed the amplitude of the global climatic signal as it is reflected in the local parameters. Even more, the consequences of these forcings may partially overlap (as is the case of the expected temperature changes or the frequency of some extreme meteorological phenomena).

The state and the quality of the ambient air in the large cities are important environmental factors which are determined by the large-scale meteorological conditions and the specific anthropogenic influences on the atmospheric environment in the form of releases of various pollutants, emissions of waste heat and changes of surface characteristics.

Sometimes, this concept is simply reduced to the term of "air quality" which expresses the amount of various pollutants in the air. Besides these features of the chemical composition, the physical (meteorological) characteristics of the urban air are equally important for the human comfort or discomfort. On the one hand, these effects and their changes originate also from the human-induced environmental impacts; on the other hand, the significance of these effects is comparable to those of the pollutants. Moreover, the physical and the chemical characteristics of the ambient air are closely related to each other; climatic and circulation conditions determine the cycle (transport, dilution, deposition, chemical transformation) of the pollutants, and some the pollutants have influence even on the local meteorological conditions.

The most apparent examples of the later relations are: the direct effects of waste heat or the excess in the aerosols on the temperature or precipitation distribution in these areas; and, the indirect effects of the pollutants on the radiation processes (atmospheric turbidity), frequency of fogs, etc. (Szepesi et al., 1977, Szepesi, 1989; Haszpra et al., 1991), whilst the air quality is interpreted as an inherent part of the urban climate much more rarely in the framework of a synthetic approach (Chandler, 1965; Probáld, 1974; Szepesi, 1981). Problems of atmospheric composition and the related chemical processes can also be treated without explicit indication of the meteorological factors in terms of cycle, balance, emission and deposition of the investigated components (Mészáros, 1977; Kiss and Gajzágó, 1988; Lévai and Mészáros, 1989; Hinrichsen and Enyedi, 1990; Bulla, 1991).

All components of the surface energy balance are influenced to some extent in the urban area as a consequence of the changes in the surface characteristics and the various man-made releases to the atmosphere (gaseous emissions, particles, waste heat). In particular, incoming solar radiation is significantly smaller in the cities because of the generally higher optical thickness. There is also an essential contribution to the heat balance from the heat release of urban energy sources. The estimates for this term in the downtown of Budapest indicate an expressed seasonal dependence in due correspondence with the enhanced energy consumption during the heating season (Probáld, 1988):

Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	annual
155	142	130	96	84	84	84	84	84	101	134	151	1327 MJ/m^2

Due to the waste heat sources during the heating season, and the reduced humidity available for evaporation in summer, the heat exchange with the near-surface air is much higher than that outside the city. This results in elevated temperatures, especially in cases of only weak vertical turbulent exchange or advection. Specific meteorological conditions in cities is primarily characterized by this phenomenon being called the heat island. As a consequence, the urban-rural temperature contrast is 1-1.5°C in average; however, under clear, calm conditions, it can reach 6-8°C. In other words, the most significant feature of the urban climate is the turbulent heat exchange between the surface and the air, with significant surpluses during the whole year. Its peak is observed during summer due decreased evaporation; a second peak occurs in January because of additional energy sources. Of these two reasons, the second is more powerful because of deeper atmospheric mixing (Probáld, 1971); that is why the maximum of the temperature contrast happens in winter:

·The surface air temperature contrast for downtown and suburb Budapest, (a) sq.Madách, (b) st.Kitaibel, (c) sq.Gilice (Probáld, 1988; period 1954-1968; °C)

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	aver
city													
(a)	-1.0	1.3	6.0	12.1	16.9	20.8	22.2	21.4	18.0	12.5	6.6	2.1	11.6
(b)	-1.5	0.8	5.7	11.8	16.4	20.3	21.6	21.0	17.2	11.7	6.1	1.5	11.0
suburb													
(c)	-2.5	0.0	4.9	11.3	16.0	20.0	21.3	20.6	16.9	11.4	5.5	0.8	10.5

•These differences are reinforced during the cold periods because of the increased energy consumption for heating:

T	[-18,	[-16,	[-14,	[-12,	[-10,	[- 8,	[- 6,	[- 4,	[- 2,	[0,
	-16)	-14)	-12)	-10)	- 8)	- 6)	- 4)	- 2)	0)	+ 2)
dT	2.7	2.4	1.9	1.8	1.5	1.4	1.1	0.9	0.8	0.7

where T denotes the daily average temperature at the suburban station, dT is the downtown-suburban temperature contrast (°C).

•Differences take place for other climatic elements, as well, however, the contrasts between the city and the surrounding climatic conditions are limited due to the circulation. This is usually determined by the macroscale circulation patterns, but in relatively rare cases of calm or very low air motion, the turbulent diffusion will be the dominant factor (Probáld, 1988). The observations for the Hungarian capital show clearly the effects of the wind for the heat island:

v	(0 ,	(0.5,	(1.0,	(1.5,	(2.0,	(2.5,	(3.0,	(3.5,	(4.0,	(5.0,
	0.4)	0.9)	1.4)	1.9)	2.4)	2.9)	3.4)	3.9)	4.9)	5.9)
dT	1.0	1.0	1.0	1.0	1.1	0.9	0.9	0.9	0.8	0.5

where the speed intervals of the daily average wind speed at the urban station (v, m/s) are tabulated and dT is the downtown-suburban temperature contrast (°C). Apparently, the effect of the wind is experienced only above some threshold value (which is about 3 m/s in our case) and the contrast "disappears" at strong winds (10 m/s and higher). It should also be noted that because of the high roughness parameter, the wind speed is generally reduced within the city which is important for the thermal comfort and the dilution of the air pollutants. The heat contrast by itself generates some pressure gradient creating some convergence towards the city center.

The elevated temperature in large cities is the most obvious feature of the heat island; other manifestations are a lower frequency of extremely cold spells in the winter period and more frequent hot days in the summer.[2] These extreme events may have significant bioclimatic consequences.

It worth mentioning the air humidity as well, because it is an essential biometeorological factor. As a consequence of the usually higher temperatures, the relative humidity is generally lower in urban areas. The annual average of this (negative) anomaly is about 4-6% with the lowest values during the summer months (Probáld, 1974).

Another important meteorological factor which essentially acts on the quality of ambient air is its vertical hydrostatic stability[3], the property which, when high, restricts vertical mixing and deep convention. The stability of the surface level layer determines the turbulent dispersion of the moisture and the pollutants emitted from the urban sources so that it plays important role in urban air quality.

•The meteorological conditions of the ambient air determine also the thermal comfort or discomfort. The main environmental conditions which effect the thermal sensation of the heat are the air and the radiant temperatures, and the air velocity over the human body (Givoni, 1989). The thermal discomfort and in extreme cases, the thermal stress should be accounted during the hot summer months. The higher temperatures during the hot spells combined with extreme values of other related meteorological factors can even increase the mortality (from the heat stress). Generally speaking, hot regions and hot seasons may mean higher heat stress levels for the population. Certainly, there might

[2] Such phenomena are well-known for a long time (Réthly, 1947): "During the hot spells in summer, the city has some nights with minimal temperatures above 20°C, and the 28th July 1928 had a minimum temperature of 23°C. In the suburbs, however, such warm nights are very exceptional."

[3] it is related to the stratification of temperature and the location of the inverse layer (or inversion). The later determines the depth of the mixing layer and as mentioned before, it is greater during the summer period, whilst the intense heat emission during the heating season causes thicker mixing layer in the city as compared to the suburban areas.

be a big difference in the impacts of "transient" and the "equilibrium" states of the varying and changing climate because of the abilities and possible rates of acclimatization (i.e., physiological adaptation).

•The thermal comfort in a narrow sense is investigated for indoor conditions; it is quantified usually in terms of effective temperature which is the function of the ambient air temperature and the humidity. In outdoor conditions, the wind and the global radiation play also important role in thermal comfort (Landsberg, 1972). Among the numerous indices applied for the evaluation of this phenomenon, the modified or corrected effective temperature is one of the most "popular" indicators (Landsberg, 1972). It reads T_{eff}=T-0.4(T-10)(1-f)+K(v,G), where T is the temperature of the ambient air (°C), f is the relative humidity and the additional term K depends on the global radiation (G) and the wind speed (v). The radiation increases and the wind decreases the thermal stress. Noteworthy that high temperature and low wind motion cause simultaneously conditions for the worse bioclimatic situation (i.e., higher discomfort) and conditions for worsening air quality (through the accumulation of the pollutants). The quantification of the effects of warmer climatic conditions on the thermal comfort is rather difficult because of the more or less correlated shifts in the climatic factors.

•The modification of the climatic (or background) conditions for the thermal comfort can also be expressed in terms of the areal distribution of the different comfort zones and in this sense, global warming might lead to the shift of these comfort zones.

•Similar approach exists for the qualification of cooling power of the ambient air. For instance, it is measured by means of the wind chill index or wind chill equivalent temperature which is dependent on the wind speed and the ambient air temperature (Landsberg, 1972; Oliver, 1973). Obviously, this parameter is frequently used for the physiological events at the cold end of the temperature scale. Because of the expected warming tendencies, the changes of climatic conditions in the urban areas which determine the cold stress are expected in the "favorite" direction, i.e., it can be assumed that the number of cases with extreme cold stress will decrease with rising temperatures.

Air quality problems are rather severe in some areas of Hungary. This is especially true for certain parts of the capital. In polluted towns and in the heavily polluted districts of Budapest, pathological alterations characteristic of children occur four times more frequently than the average. In this relation, the occurrence of adult chronic bronchitis is three times that of the average (MER, 1991).

The main polluters of the atmospheric environment usually are the energy sector, traffic, chemical factories and raw material production (cement or aluminum). As concerns the local sources of pollutants, the air quality of the capital is primarily determined by the emissions from the energy sector (power plants, end users) and the rapidly increasing traffic. At present, these sources of air pollution are responsible for the release of about 410 kt dust (particulate matter) and soot, 280 kt NO_x, 1200 Mt SO_2, to which must be added a significant amount of hydrocarbons and lead from vehicles (Bulla, 1991). 40-45% of emissions are of industrial origin, 30-35% is attributable to transportation (vehicles), and about 20% comes from residential heating. At present, the trend is for decreasing pollution from industry, but increasing contributions from traffic.

Eastern Europe is considered as one of the regions where the air pollution is rapidly increasing. Of course, there are significant differences in the environmental quality and the environmental policy among the countries of the region; that is the case for air quality problems and the emission of the greenhouse gases and other pollutants. One of the most important reasons of this situation is the low energy efficiency in the countries of the region (Chandler et al., 1990; KSH, 1987). Obviously, this is also related to the energy sources available and used in the given country. The relatively low use of solid fossil fuels in Hungary explains the relatively low emission rates as compared to some other Eastern European countries (Lévai and Mészáros, 1989):

Annual CO_2 emissions Mt-C (1982, except +1987)					
	Gas	Liquid	Solid	Total	tC per capita
Czechoslovakia	3.847	12.946	47.118	63.9	4.34
GDR	4.409	14.413	64.183	83.0	4.90
Hungary+	5.395	7.984	10.545	23.9	2.24
Poland	4.833	10.813	96.337	112.0	3.31
Roumania	21.619	12.460	16.836	50.9	2.42

This problem is amplified in large cities during the heating seasons. The energy used for space conditioning by burning fossil fuels (primarily for heating) has increased to 30-40% over the last 30 years. It determines the higher releases of sulfur dioxide, methane, carbon-monoxide etc. More specifically, 1235 PJ energy was used in Hungary in 1990, which is less by 81.3 PJ as compared to the energy consumption in 1989. As concerns the energy sources, the share of coal was 22.2% in 1990 (19.1% in 1989) and that of the natural gas was 28.3% (28.4%); the coal is mainly used for power generation ("far" from most city areas).

For climate impact studies, it is important to note that the directly climate-sensitive part of the energy consumption is about 20 PJ/°C, which is a function of the average temperature for the heating season (Garbai, 1990). That part of the pollutant emission which is related to heating energy consumption in urban areas is more or less linearly proportional to that energy amount, which dependence on the winter conditions is usually expressed in terms of heating degree days (Szepesi, 1981).

Sulfur dioxide is considered as the common indicator of the air quality. It is mainly released from burning fossil fuels. Consequently, the highest emissions usually occur during the heating season. Several decades ago the high sulfur-content of fossil fuels should have been considered as the dominant reason of the low air quality in Budapest. In the period of 1963-1968, the average sulfur content of the brown coal intensely used for power generation was 2.0-4.5%, and that of the oil was 1.0-2.8% (Probáld, 1974); the latter is now much smaller but more than twice as much than that in Western Europe. Moreover, from the burning of these fossil fuels, high particulate emission occurs. During the indicated period, annually 250 kt sulfur was emitted from the capital. This resulted in the extremely high SO_2 concentrations in Budapest: 680µg/m3 during 1958-1960. After this period, the share of the natural gas rapidly increased and the SO_2 concentrations in annual average dropped to 270 $\mu g/m^3$ (410 $\mu g/m^3$ for the winter half-years; these are observed values for 1969-1971).

The sulfur content of the "local" brown coal is relatively high, at an average of 2.2%. That of the oil imported from the Soviet Union is 1.6% (Kiss and Gajzágó, 1988). Nevertheless, the measures taken to cope with the pollution problems (namely, the limitation of burning coal with high sulfur content in the capital; decrease of the use of solid energy sources; import and use of more natural gas) have resulted in further significant reduction of the SO_2 concentrations to an average value of 13 $\mu g/m^3$ in 1988 (Bulla, 1989). This expresses annual and area average, so that in certain parts of the capital and in certain periods, much higher concentrations are observed.

The problem of the sulfur dioxide (and some other pollutants) has also larger-scale aspects because of its transboundary transport and the role in forming the acid rain. According to the international convention, Hungary has committed to reduce overall SO_2 emissions; in this regard, the annual emissions in Hungary have fallen are from 1633 kt in 1980, to 1420 kt in 1985, with 1140 kt projected for 1995 as required by the convention.

Apart from energy consumption for air conditioning or industrial production, the transportation is the other major source of pollutants in urban areas. This sector has had an extraordinarily rapid development for the last thirty years. Number of cars exceeded 100,000 at the beginning of the 1970s and was about half a million at the end of that decade. Low fuel efficiency has been characteristic for the majority of the internal combustion car engines and even recently there is only a "symbolic" share of cars with low fuel consumption or catalytic converters. This has lead among other problems to rapid increases of the NO_x emissions and because of the high number (about one third) of cars had two-stroke engines, it resulted in considerably higher hydrocarbon and formaldehyde emissions.

Transportation has become, in some cases, the highest source of pollutants for the last two decades: 45-50% of CO-emissions, 40-45% of NO_x-emissions, and 90% of lead emissions originated from this sector in 1988. Due to the intensive car traffic, the air quality in the city and along the busy streets has worsened in recent years. "Measurements at congested road intersections in Budapest demonstrate that concentrations of carbon monoxide and lead exceed many times the permissible limits, while formaldehyde concentrations are beyond the permissible limits in half the measurements." (Hinrichsen and Enyedi, 1990). Elevated concentrations of carbon monoxide and lead pose the most serious pollution problems for Budapest. Before 1985 the lead content of petrol was 0.6-0.7 g/l, then it was limited to 0.4 g/l (due to the completion of a catalytic cracking plant in 1985). Projections are that it will not exceed 0.15 g/l by 1993. The local government of Budapest decided to reduce by 50% the average level of air pollution within four years and, more specifically, the lead content in the air by 90%. Unfortunately, the use of unleaded petrol is currently limited by its production which was 45,000 t in 1990 and will be 90,000 t in 1991. Further investments are planned to increase this annual amount to 300-500,000 t; however, its overall requirement is about 1.5 Mt.

The strike of the taxi drivers at the end of October 1990 provided a very special "experiment" for the analysis of air quality and its anthropogenic sources in the capital. This three days event, which began during the night of 25 October, froze the transportation in the heart of the city. According to the measurements made at the locations of usually heavy traffic (sq. Erzsébet (a) and sq. Széna (b)), the anthropogenic "load" on the urban environment is overwhelming:

Daily total amount of pollutants								
	(a)				(b)			
days (October, 1990)	25	26	27	28	25	26	27	28
SO_2 (µg/m^3)	136	89	37	15	83	69	35	16
NO_2 (µg/m^3)	119	106	59	49	116	84	43	35
CO (mg/m^3)	4.6	2.7	1.3	1.3	5.0	2.5	1.3	1.5
Dust (µg/m^3)	148	137	115	75	180	177	129	83

(Of course, the SO_2 is not attributed to the vehicles.) The official (mandatory) emission norms are as follows: 150µg/m^3 for SO_2, 85µg/m^3 for NO_2, 5mg/m^3 for CO, 50µg/m^3 for soot.

Haszpra et al. (1991) pointed out that besides the regularly measured air pollutants, releases of other materials provide also high concentrations. The primary sources of hydrocarbons in urban areas is the automobile traffic; aldehyde is also partially produced in the combustion of hydrocarbon fuels and indirectly in the atmospheric photo-oxidation of these fuels. The average concentration of the non-methane hydrocarbons (like ethylene, ethane etc.) usually reaches its maximum between during the morning peak period for traffic.

The above-mentioned primary pollutants, under certain meteorological conditions, may be transformed to even more harmful materials or secondary pollutants. The most significant of these processes is that related to the ozone and the photochemical smogs. Earlier, the occasional appearance of the reductive or London type smog was the consequence of the accumulation of the sulfur compounds and soot in the air because of the ineffective heating technology and high sulfur-content of the energy sources. At present, the hazard of photochemical or Los Angeles type smog during the summer is more realistic. This is characterized by high concentrations of oxidants (primarily ozone), the precursors for which are the car-emitted NO_x and hydrocarbons.

Toxic materials in the air lead to high exposure of persons to them, especially along the busy streets. This creates hazards to health. Lung damage, developmental problems for children, and connections to various diseases have all been demonstrated. There are 24 times more patients now suffering from asthma than two decades ago, the number of those with lung cancer has doubled for that period. Those are clear indicators of the worsening air conditions in Budapest. One of the most dangerous pollutants is lead.

IMPACTS OF CLIMATE CHANGE ON AIR QUALITY

While the level of uncertainty in the specification of future climate scenarios for specific urban areas is high, the uncertainty level in the assessment of "second order" impacts of such change on air quality and human health is even higher.

•The estimated changes in the climatic elements in urban areas can influence the environmental comfort or stress as a whole and the thermal comfort or discomfort, in particular. As mentioned before, the problems may arise first of all during the summer season with the increasing air temperatures. Obviously, the increasing surface air temperatures provide a big potential for strengthening of the thermal discomfort. The expected decrease in the cloud cover and increase in the irradiation will reinforce these impacts, whereas the estimated reductions in the relative humidity counteract to this tendency. Of these factors, the increase of the temperature is dominant so that eventually, at average, the worsening conditions of the thermal stress are expected if the climate scenarios are properly interpreted for our region. (Actually, the impacts on the natural ventilation within the urban area, which is also an important factor in the thermal sensation, cannot be assessed.) The most that can be extracted from the regional scenarios is that the frequency of the zonal circulation patterns will probably decrease and the cases of thermal instability with increasing surface temperatures will increase (Mika, 1989), which may also have effects on the average wind speed in the boundary layer.

•Assessments can also be made about the number of threshold events if the mean values or variability characteristics of the investigated climatic elements change. These studies (Mearns et al., 1984; Balling et al., 1990; Katz, 1991) indicate that the number of extreme events behaves in a nonlinear way depending on the changes in the mean parameters. Consequently, higher mean surface temperature causes (or appears in the form of) exponentially increasing number of hot days (with temperature exceeding certain levels).

Air quality at the most basic level concerns the composition of the atmospheric environment; the focus is usually on concentration of those components that have adverse effects on people and their environment. It should be noted that some of the gaseous releases responsible for the increasing greenhouse effect act also as pollutants. Other pollutants may have no greenhouse effect, but affect air quality, e.g. by participating in photochemical reactions, which lead to smog. These connections also mean that some of the impacts of the climate change on the emission of the pollutants and the air quality as a whole can create a feedback mechanism.

The cycle of the air-borne toxic materials is closely related to certain meteorological factors. It affects, among other aspects, their emission, chemical reactions, transmission, dilution, and dry and wet deposition. Climate change can thus affect the pollution, the smaller-scale air quality. Impacts can be categorized as to their effects on the chemical processes or the physical conditions of what happens to pollution in the atmosphere. As concerns the chemical aspects, apparently, the most important point is that, the chemical reactions will accelerate under the warmer conditions. In this respect, two processes may have significant consequences. On the one hand, higher temperatures provide favorite conditions for the more frequent and intense formation of the ozone from its precursors; on the other hand, the higher oxidization rate can lead to the more intense formation of the particulate matter (sulfate aerosols). If the intensity of the large-scale circulation changes with global warming, this could lead to more frequent and persistent periods during which pollution can accumulate and linger over urban areas, stimulating more serious smog episodes.

The possibility of higher probabilities for the occurrence of smog of both types is emphasized by Antal and Starosolszky (1990): "With the rising frequency of anticyclonic situations smogs are expected to recur more often in the big towns, particularly in weather situations when weak air currents may lead to the development of 'cold air-cushions'." The possibly increasing irradiation will contribute to these processes (IPCC-WG-II, 1990): "Global warming and increased ultraviolet radiation resulting from depletion of stratospheric ozone may produce adverse impacts on air quality such as increases in ground-level ozone in some polluted urban areas."

Changing climatic elements influence the emission of air pollutants, as well. The most climate sensitive part of the energy demand is that used for space conditioning. In Hungary, more than 30% of all energy consumption is used for residential heating and it closely depends on the heating degree days (HDD) for the heating season (Ambrózy and Faragó, 1988). The average temperature for the given period determines the HDD.

•Simple linear regression scheme has been derived by Vértesy (1984) for Budapest between HDD(T) and T, so that the decrease of the heating energy demand in case of the hypothetical increase of winter temperature or heating season temperature can be easily assessed. The changing amount of emissions can also be related to the HDD by use of specific emission factors (Szepesi, 1976).

Since the temperature changes influence the energy consumption, and the anthropogenic emission of hydrocarbons, NOx, sulfur oxides are directly related to the use of fossil fuels, it means that changes in emission rates depend on temperature changes.

•Typically, the "background" level of the atmospheric carbon dioxide is not considered as an important indicator of the air quality, however, it is not neutral at all in terms of its role for the ecosystems. Consequently, the concept of the air quality should not limited to the toxic components released to the atmosphere. The enrichment of the CO_2 content in the atmosphere as one of the causes of the human-induced climate change, acts also as a "fertilizer" and consequently it will have its direct environmental influences at large and in particular, in the urban areas.

Dilution of the polluting materials depends on the strength of circulation and turbulent diffusion. In this regard, three features of the ambient air in urban areas should be mentioned: the wind speed, the mixing depth and the vertical stratification (or stability) of the near-surface air column. In correspondence with the regional scenarios for the Central European region, the possibly of reduced large-scale advective processes may result in the reduced ventilation within the city. Of course, in case of advective motions, the direction of the wind speed is also of significance: it determines the origin of the air and the air-borne pollutants arriving at the city.

High pressure synoptic patterns usually create favourable conditions for low level inversions, and the accumulation of pollution from local sources.[4]

•The fact is remarkable that the key sources of the man-made climate change more or less coincide with the origins of the air quality problems. It is valid both for the emissions and the damages caused to the vegetation cover. Of course, the scales and the emitted materials only partially overlap. Especially, on the one hand, the main sources of the air quality problems in the large inhabited areas are the emissions from the energy sector, industrial production (primarily, that of the chemical plants) and the transportation. On the other hand, the vegetation cover is an important factor of the air quality (and environmental quality, in general) in these areas. Besides the greenhouse gases, there are certain

[4] Climate change can also affect the deposition of the pollutants: the expected decrease in the summer precipitation may lead to worse conditions of wet deposition of the pollutants.

toxic materials emitted. Consequently, the necessary control measures are more or less the same as those for global warming at large, however, in case of local air quality problems, the level of uncertainties is much lower. Therefore, most elements of the general response strategies for the greenhouse effect can be "simply" repeated. Those include "phasing out the production of and use of CFC's, efficiency improvements and conservation in energy supply and use, appropriate measures in the transportation sector, ... the use of safe and cleaner energy sources with lower or no emissions of carbon dioxide, methane, nitrous oxide and other greenhouse gases and ozone precursors" (SWCC, 1990). These measures should be "transformed" to local city scale and some other policy elements should also be added. Some of these local scale elements of the potential responses have also been formulated (IPCC-WG-II, 1990): "In developed countries some of the greatest impacts on the energy, transportation and industrial sectors may be determined by policy responses to climate change such as fuel regulations, emission fees or policies promoting greater use of mass transit." Similarly, there is an urgent need for the further reduction of the emission of industrial and communal pollutants in Hungary; the required measures regard also the existing power stations and the control of car emissions (MER, 1991).

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